Flux Density and Power Loss Distribution in 100kVA Distribution Transformer Core Assembled with Different Cutting Angle of T-Joint

By

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A thesis submitted in fulfillment of the requirements for the degree of
Master of Science (Electrical Systems)

School of Electrical Systems Engineering
UNIVERSITI MALAYSIA PERLIS

2010

UNIVERSITI MALAYSIA PERLIS

DECLARATION OF THESIS

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Academic Session	:	2009-2010

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Acknowledgements

The work has been carried out at the School of Electrical System Engineering, Universiti Malaysia Perlis.

I would like to express my gratitude to Professor Dr. Ismail Bin Daut who supervised and also for the guidance and valuable discussion during the research.

Special thank to Professor Madya Dr. Soib Bin Taib from Universiti Sains Malaysia, for the incessant encouragement and also for valuable discussion.

I would like to thank En. Shahanom Bin Uthman, Malaysian Transformer Manufacturing and TNB Research for the providing of the 1000kVA Distribution Transformer core and the grain oriented silicon steel (CRGO 3% Si-Fe), for commercial name known as M5 used in this research.

I am grateful to all the staff and students at the School of Electrical System Engineering, Universiti Malaysia Perlis for their help, discussion and friendly atmosphere throughout my studies.

Finally, I would like to appreciate the inestimable support, patience and encouragement which I received from my family.

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B	Maximum flux density in the core in Tesla
B_r	Remanence or residual flux density
B_{peak}	A peak flux density
B_{max}	Maximum flux density
B_m	Flux magnitude
B_c	Flux magnitude of circular
B_x	flux in x direction
B_y	flux in y direction
H	Magnetic field strength
M5	Grain oriented silicon steel sheet's grade
μ	Permeability
μ_{in}	Initial permeability
μ_m	Maximum permeability
μ_o	Permeability of free space
μ_r	Relative permeability
A/m	Magnetic field strength unit
H/m	Permeability of free space unit
H_{in}	Internal magnetic field strength
H_{app}	Applied magnetic field strength
H_d	Demagnetising field strength
H_c	Coercive force
Hx	Magnetic field strength in x direction
Hy	Magnetic field strength in y direction
N_d	Demagnetising factor
M	Magnetisation of material
f	Frequency in hertz
V	Voltage
T	Tesla
W	Watt
J	Polarization
J_r	Residual polarization
Fe	Iron

Co	Cobalt
Ni	Nickel
S	Overlap region
g	Air gap length
a	Overlap length
Φ_g	Flux air gap
Φ_s	Flux overlap
W_H	Energy
W_E	Excess loss
k	Constant
$Wn_{classical}$	Classical eddy current loss
t	Sheet thickness
β	Geometrical factor
p	Resistivity
P_e	Eddy current loss
P_{tot}	Total power loss
P_h	Hysteresis loss
P_a	Anomalous loss
D	Density
d	Thickness
L	Live
N	Neutral
L_1	Live 1
L_2	Live 2
L_3	Live 3
L_R	Live red
L_Y	Live yellow
L_B	Live blue
I_p	Primary current
V_s	Secondary voltage
R	Red phase
Y	Yellow phase
B	Blue phase
I_{PR}	Primary current red

I_{PY}	Primary current yellow
I_{PB}	Primary current blue
V_{SR}	Secondary voltage red
V_{SY}	Secondary voltage Yellow
V_{SB}	Secondary voltage blue
Ch1	Oscilloscope channel 1
Ch2	Oscilloscope channel 2
N	Number of turn
A	Cross section area
dB/dt	Rate change of flux density
V_{rms}	RMS Voltage
V_{ave}	Average voltage
CT	Current transformer
V	Voltmeter
A	Ammeter
W	Wattmeter
G	Alternator
741	Operational amplifier IC
ADC	Analog to Digital convertor IC
LCD	Display type
8085	Microcontroller IC
Kg	Kilogram
W	Watt
W/Kg	Watt/Kilogram
AC	Alternating Current
DC	Direct Current
RM	Ringgit Malaysia
B.F	Building factor
FEM	Finite Element Method
TNB	Tenaga Nasional Berhad
TNBD	Tenaga Nasional Berhad Distribution
SESCO	Sabah Electricity Supply Company

Pembahagian Ketumpatan Fluks Dan Kehilangan Kuasa Pada Teras Alat Pengubah Pembahagian 100kVA Sambungan-T Yang Berbeza Sudut

Abstrak

Kehilangan kuasa yang terhasil daripada permagnetan telah mendapat perhatian sejak dari dahulu lagi. Alat pengubah yang dibina daripada sambungan-T Butt Lap menghasilkan kehilangan kuasa paling tinggi. Ini kerana fluks terpaksa berpusing arah sebanyak 90º di dalam kawasan arah susah dan perlu naik dan turun ke lapisan bersebelahan menyebabkan kehilangan kuasa yang tinggi terhasil pada sambungan-T ini. Untuk mengatasi masalah ini, beberapa jenis potongan bersudut seperti 23º, 45º dan 60º diperkenalkan di dalam usaha untuk menghasilkan rekabentuk yang lebih baik. Pembinaan model teras alat pengubah pembahagian 100kVA untuk pengukuran kehilangan kuasa dan faktor pembinaan telah dibuat dan ekperimen telah dilakukan untuk menunjukkan sambungan-T yang mana dapat menberikan kehilangan kuasa paling minima dan faktor pembinaan terbaik. Ketumpatan fluks setempat diukur dengan menggunakan "search coil" untuk menunjukkan pembahagian ketumpatan flux setempat pada sambungan tepi dan sambungan-T. Ketumpatan fluks harmonik asas, fluks harmonik ketiga dan fluks harmonik kelima pada fluks normal dan fluks inplane telah diukur di sambungan tepi dan sambungan-T. Kehilangan kuasa setempat diukur dengan menggunakan "thermistor" pada lokasi yang sama dengan "search coil". Keputusan menunjukkan bahawa kehilangan kuasa paling minima, faktor pembinaan terbaik, ketumpatan fluks untuk fluks normal, fluks harmonik asas, fluks harmonik ketiga, fluks harmonik kelima pada fluks normal dan fluks inplane serta kehilangan kuasa setempat adalah paling rendah pada model teras alat pengubah sambungan-T 60°.

Flux Density And Power Loss Distribution In 100kVA Distribution Transformer Core Assembled With Different Cutting Angle Of T-Joint

Abstract

The power losses occurring under magnetising condition have received a great deal of attention for a long time. The transformer designs with Butt Lap joint cause the highest power loss at the T-joint. These due to the flux need to rotate 90º into the hard direction and transfer up and down to the adjacent layers causes high rotational power loss occurred at the T-joint. To overcome this problem, the different cutting angle such as 23º, 45 º and 60º at the T-joint was introduces in order to find out the most efficient design. The development of the 100kVA Distribution Transformer model core with the four difference types of the T-joint for the power loss and building factor measurement has been tested in order to find which T-joint has minimum power loss and better building factor. The localised flux density was measured using the search coil in order to find out their distribution at the corner joint and T-joint. The fundamental, third and fifth harmonic in the normal and inplane flux density were measured at the corner joint and T-joint. The localised power loss was measured using the thermistor at the similar location of the search coil. The results show that the minimum power loss, better building factor, the minimum fundamental, third and fifth harmonic the normal and inplane flux density and also minimum localised power loss are occurred at the transformer model core assembled with the 60° T-joint.

Chapter One
Introduction

1.1. Introduction

For a long time industry and academia have been working to improve the methods for predicting losses in the laminated transformer cores. The important research findings have been reported over the last decades based on modern numerical techniques for the field calculation and prototype testing (Jose F.d.O, 2000). This work is an attempt to compile much of the available information about the losses in the laminated cores and to elaborate the less loss but still in the practical tool for possible application in the transformer industry.

Mostly, the magnetic cores of the three phase transformers work under the alternating magnetisation but the different type of the magnetisation is produced in the T-joint of the three limb three phase transformers. It has been widely reported that in these regions, the magnetic material is subjected to the rotational magnetisation (Radley B., 1981, Kanada T., 1996). The magnetic excitation which produces the rotational and alternating magnetisation at arbitrary direction within the plane of the lamination is called as the two dimensional magnetisation. If the excitation causes the rotation of the flux density vector, then the magnetisation is also referred to as the rotational magnetisation. The core losses in the laminated cores are estimated to dissipate over 3% of all generated electricity (Moses A.J., 1992). The measurement of the power losses under the alternating magnetisation conditions are precisely defined by the international standards (IEC, 1996). It is attempted to measure the magnetic properties of the magnetic material under the circular flux density or magnetic field (Stanislaw Z., 2005). This study is focused on the stacked laminated cores and to suit an appropriate sample of tested units, restricted to the three phase three limb cores built from the grain oriented silicon of the high permeability steel at 50 Hz. The range of the flux densities chosen for the analysis is 1.0 T to 1.8 T. The intention of covering is not only the usual operating condition but also in the special cases where the low induction (1.0 T to 1.3 T) is required and also the temporary overfluxing with the transformer operating close to saturation levels (1.7 T to 1.8 T).

1.2. The Aim Of This Research

The aim of this research is to investigate the influence of the different cutting angle of T-joint on the power loss and flux distribution hence will found which type of the cutting angle of T-joint with the lowest power loss on the transformer core lamination.

In summary, the works have been done for this research are to design, develop and construct the 100kVA Distribution Transformer core model assembled with the Butt Lap joint, 60º T-joint, 45º T-joint and 23º T-joint. Method that use in the investigation is the No-Load Test by arrays of the search coil. The nominal power loss for the core material is measure using the Epstein Test Frame. From the result of the nominal power loss and the actual power loss measurement will be found the building factor for each transformer core model. The Single Sheet Tester was used to find the flux in the easy and hard direction. The localised power loss for each point in the lamination of each cores model has been measured by using the temperature rise technique with the thermistor. The path way of the flux travels in the core of each type of the T-joint was simulated by using the Finite Element Method of the QuickField software. The mesh and contour graph of the localised fundamental and harmonic flux density of T-joint core was drawn by using the Matlab software and also the mesh and contour graph of the localised power loss at each T-joint.

Chapter Two

Magnetic Properties, Flux Distributions And Losses

2.1. Magnetic Properties Of Ferromagnetic Materials

The magnetic properties of a given material can be divided into two groups. The first group belongs to those properties such as the saturation magnetisation and the saturation magnetostriction. These properties are the fundamental constants with the ferromagnetic element or its alloy. The second groups are those properties which depend on the structure and previous history of a given material. The structure sensitive properties include the permeability, remanence, coercive force and magnetostriction.

The magnetic properties of the material can be described as the magnetisation and domain theory, magnetisation curve, demagnetising field, magnetocrystalline anisotropy, the magnetism and rotational magnetisation, the alternating magnetisation, the rotational magnetisation and the soft magnetic materials in the rotational magnetisation.

2.1.1. The Magnetisation And Domain Theory

The magnetisation curve can be described in the terms of the domain theory. It is convenient to treat the curve in the three main parts and explain each part in terms of the domain theory (D. Jiles, 1996). Figure 2.1 shows the domain processes occurring as the material is magnetised to saturation. The first part called initial part which the domain process occurs which is a growth of domain which are align favourably with respect to the field and a consequent reduction in size of domains which are aligned in direction opposing the field. The second part called middle part which the mechanism becomes significant, this is domain rotation in which the atomic magnetic movements within an unfavourably aligned domain overcome the anisotropy energy and suddenly rotate from their original direction of magnetisation into one of the crystallographic easy axis which is nearest to the field direction. The third part called upper portion which the domain process coherent rotation takes place. In this process the magnetic moments, which are aligned along the preferred easy axis lying close to the field direction are gradually rotated into the field direction as the magnitude of the field is increased. Figure 2.2 and 2.3 show the domain wall structure of the grain oriented silicon steel, M5 magnify by 500X and 300X.

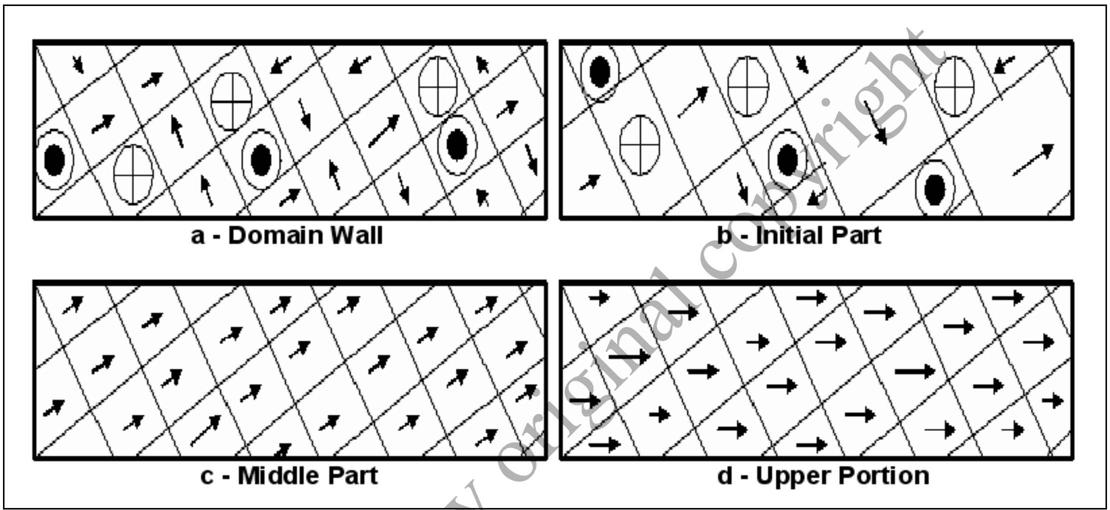

Figure 2.1: Domain processes occurring as the material is magnetised to saturation

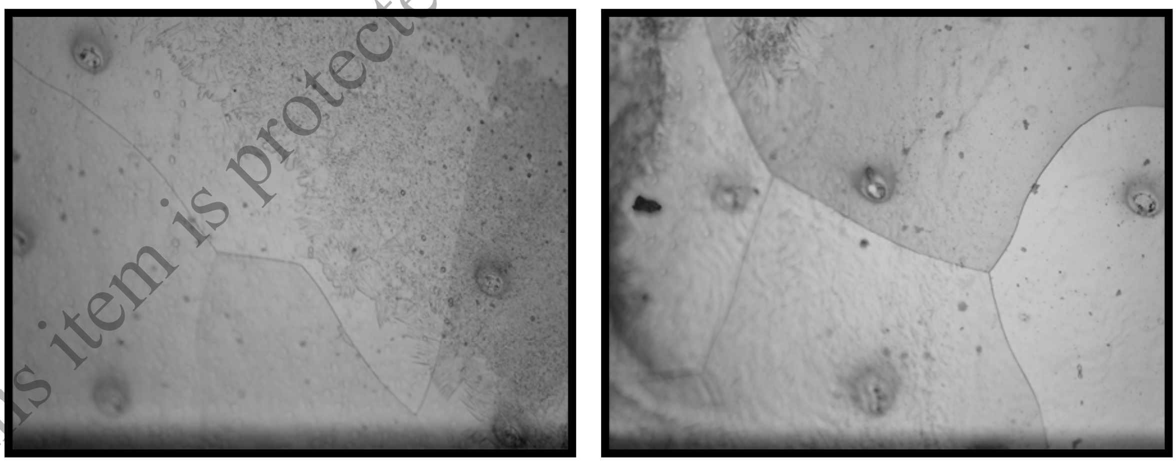

Figure 2.2: Domain wall structure of M5 magnify by 500X

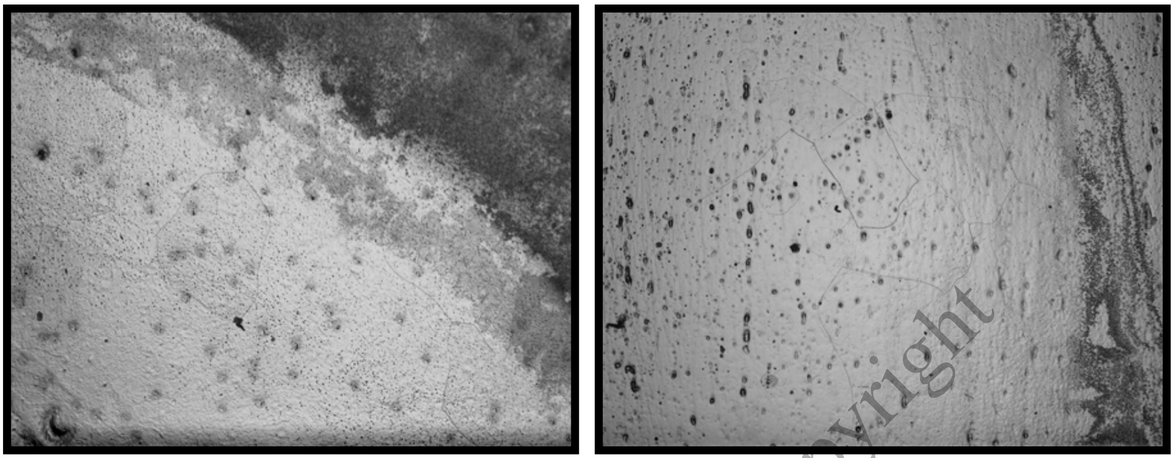

Figure 2.3: Domain wall structure of M5 magnify by 300X

2.1.2. Magnetisation Curve

The curve which relates the induction, ***B*** to the field strength, ***H*** is called the magnetisation curve. This curve is important because it can find the permeability, μ at any values of the ***B*** or ***H*** as well as the initial and the maximum permeability which are often used for the comparative purposes. The permeability, **μ** is the ratio of the ***B*** over ***H***. The initial permeability (μ_{in}) is found from the slope of the B-H curve at the low fields. The maximum permeability (μ_m) is the maximum value found by dividing the ***B*** by ***H***, graphically is the slope of the line from the origin to the point on the knee of the curve. At the large values of the ***H***, the material becomes saturated and at the saturation limit the curve becomes the horizontal line (B.D. Cully, 1972). Figure 2.4 shows the ***B*** versus ***H*** curve of the ferromagnetic material.

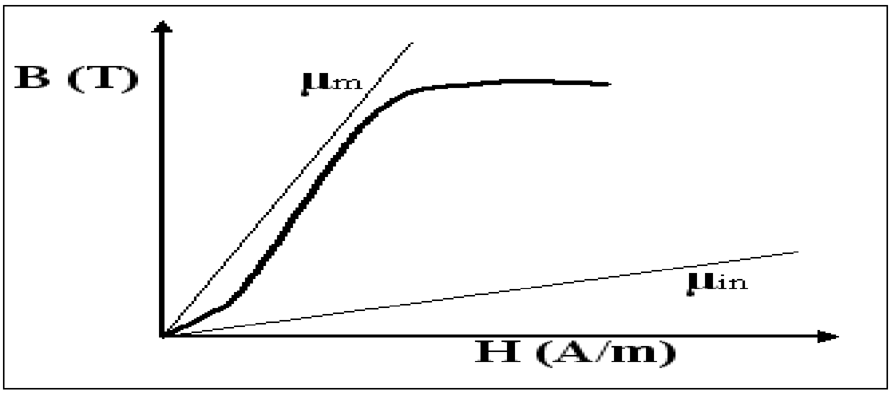

Figure 2 4: The B versus H curve of the ferromagnetic material

2.1.3. Demagnetising Field

It is necessary to consider the demagnetisation factor in the ferromagnetic materials. The exact internal field in the ferromagnetic material is made up of two parts,

$$H_{in} = H_{app} - H_d \qquad \textbf{(2.1)}$$

Where $\boldsymbol{H}_{\mathbf{app}}$ represents the applied magnetic field outside the specimen and $\boldsymbol{H}_{\mathbf{d}}$ represents the demagnetising field and depend on the magnetisation in the material and the shape of the specimen [2.2]. It is expressed in

$$H_d = N_d M \qquad \textbf{(2.2)}$$

$\boldsymbol{N}_{\mathbf{d}}$ is the demagnetising factor which is calculated from the sample geometry.

2.1.4. Magnetocrystalline Anisotropy

When the ferromagnetic material is subjected to an applied field, the observed magnetisation depends on the both magnitude of the field and the crystallographic direction along which it is applied. The large field of the magnetisation will reach the saturation value which is the same for all crystallographic directions. This shows that all magnetisation vectors have been rotated as to be parallel to the applied field. The crystallographic direction for which the magnetisation reaches saturation in the lowest applied field is known as the easy direction of magnetisation or the easy axis of magnetisation. This is the axis which the magnetisation vectors of the domains lay in the absence of an applied field (George L., 1998). Figure 2.5 shows the magnetisation curves in the various crystallographic directions to illustrate the magnetocrystalline anisotropy of the iron